(12) UK Patent Application (19) GB (11) 2 191 229 (13) A

(43) Application published 9 Dec 1987

(21) Application No 8607215

(22) Date of filing 24 Mar 1986

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(51) INT CL[4]
E21B 43/01

(52) Domestic classification (Edition I):
E1F JB
B8E 10

(56) Documents cited
GB A 2168939 GB 1562113 US 3504740
GB A 2149371 GB 1547092

(58) Field of search
E1F
B8E
Selected US specifications from IPC sub-class E21B

(54) Offshore hydrocarbon production system

(57) This invention provides an offshore hydrocarbon production system comprising a subsea manifold connectable to satellite wells, and a riser extending from the manifold to a surface production buoy which is tethered over the manifold and maintains the riser in tension. The seabed manifold preferably has a vertical axis around which the valves are radially disposed for service or operation by a remotely operated tool moveable into and out of the manifold along this axis.

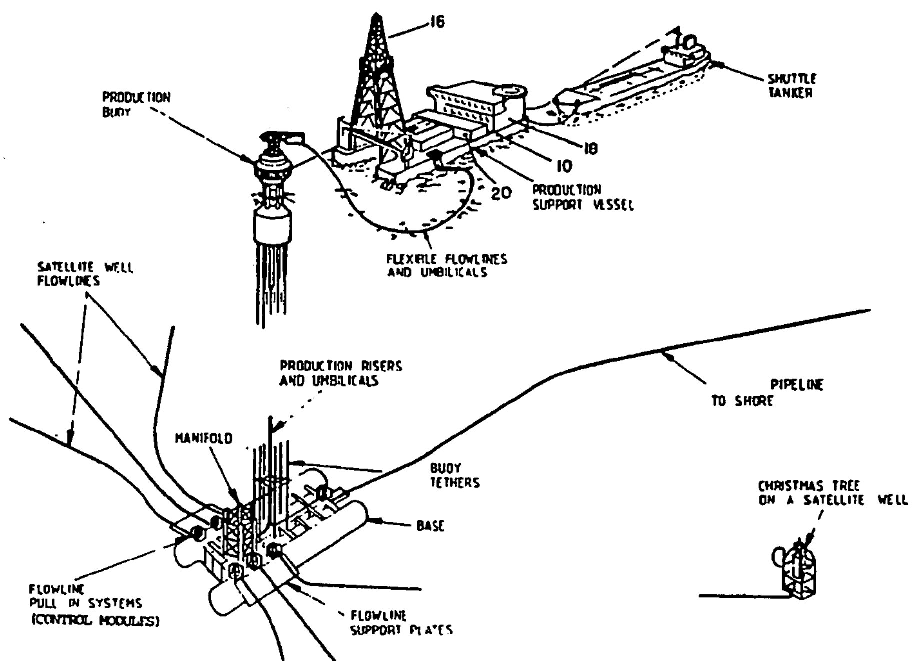

FIG. 1

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The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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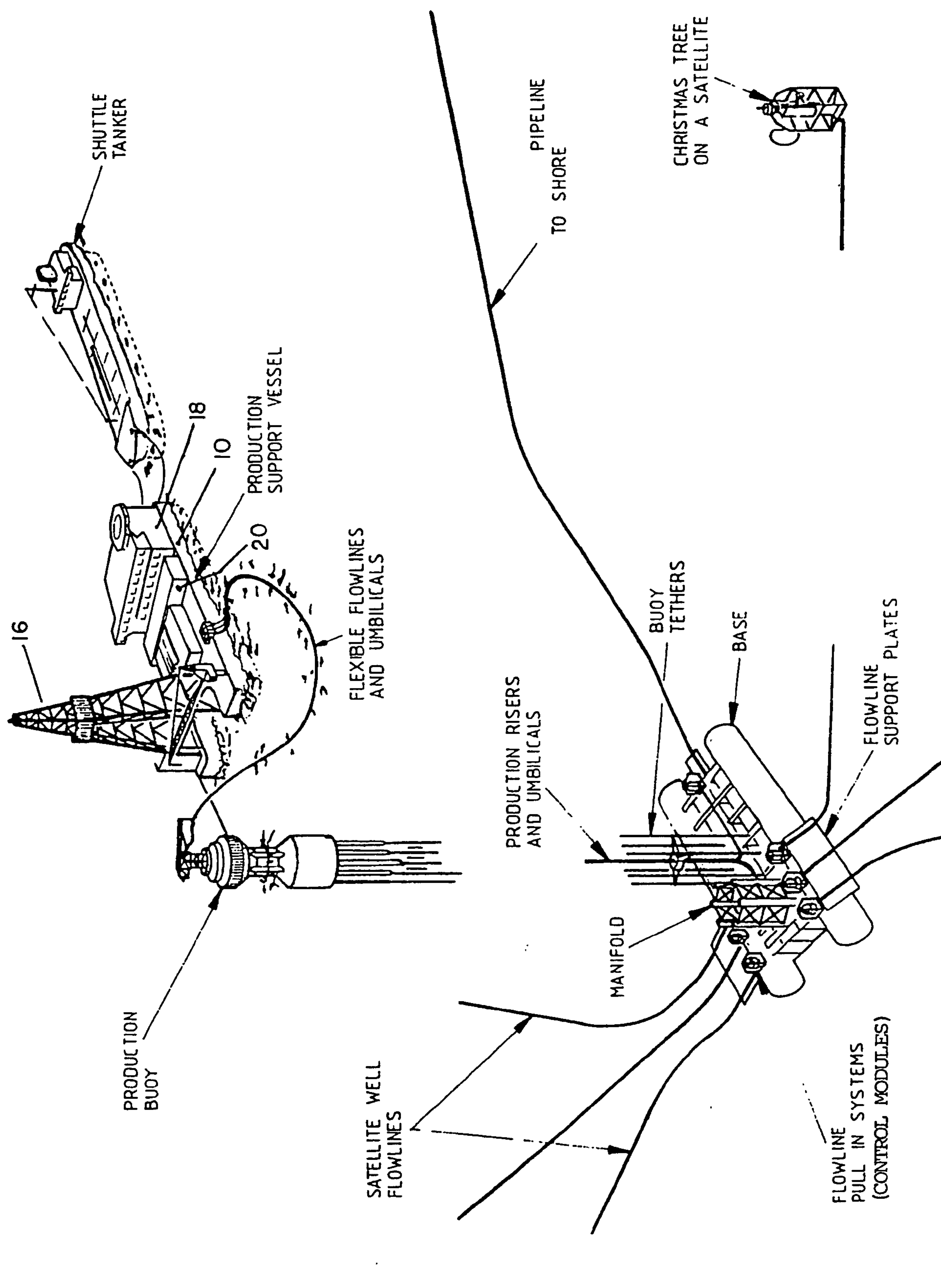

FIG. 1

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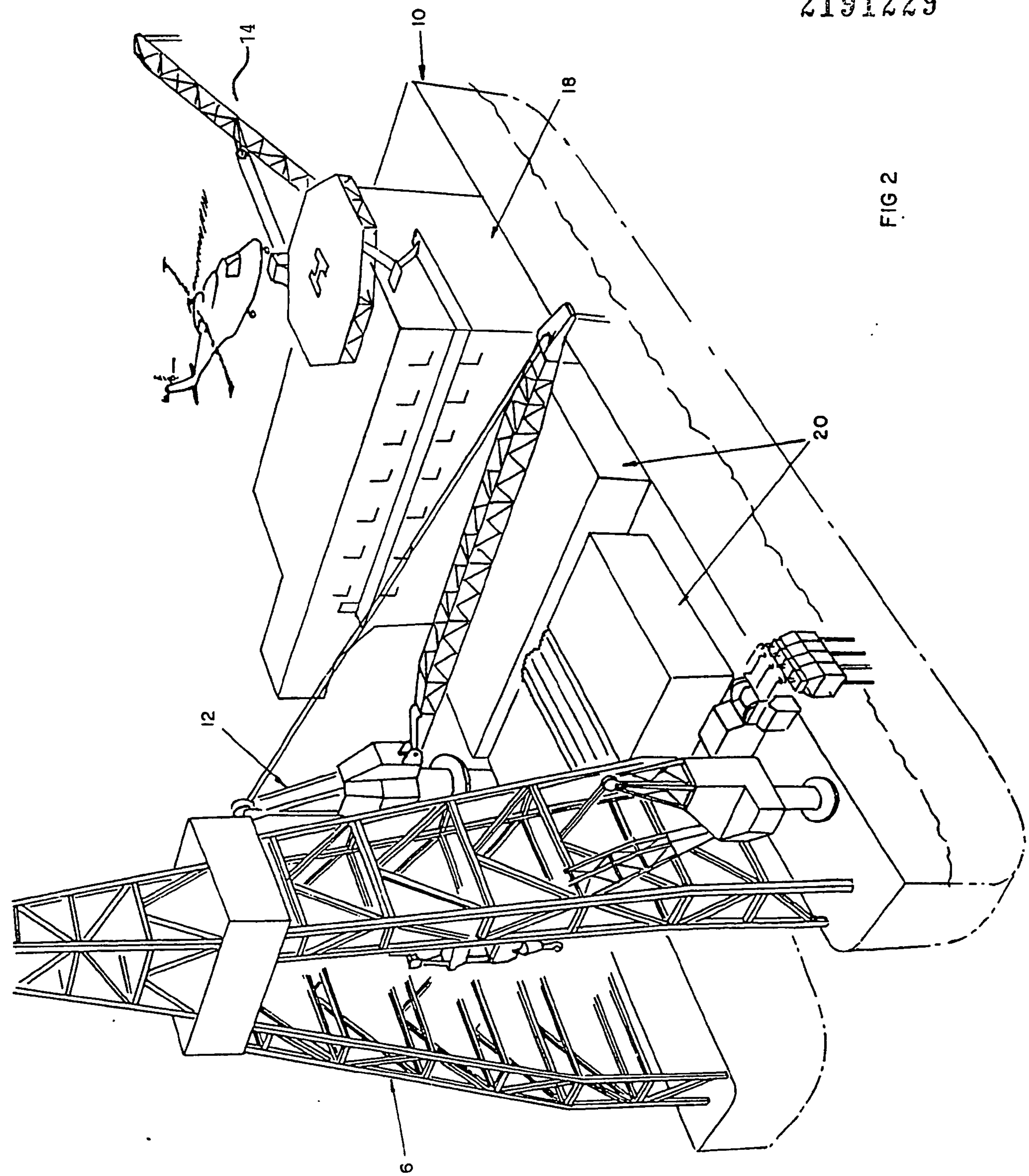

FIG 2

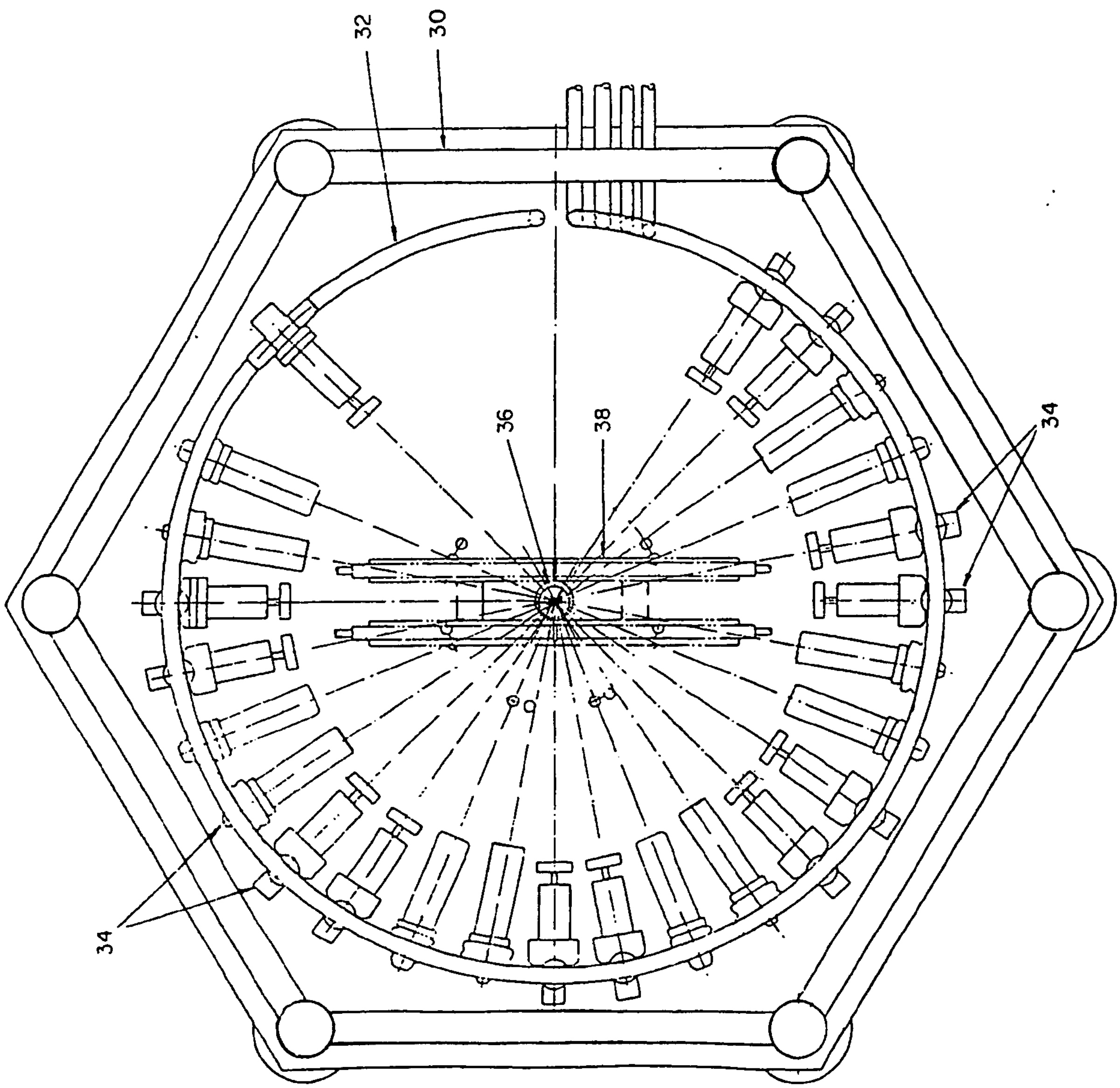

FIG.3

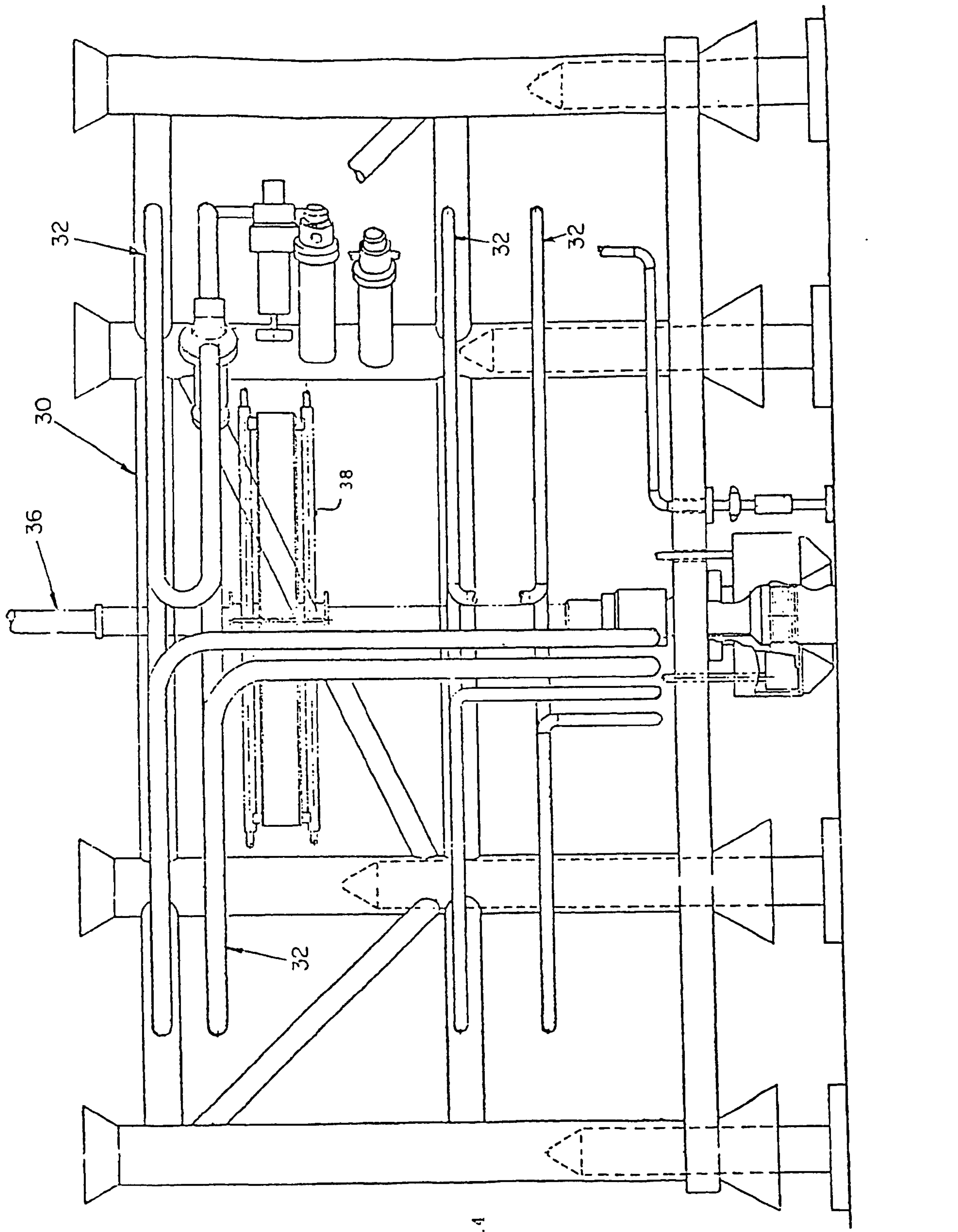

FIG.4

SPECIFICATION

Offshore hydrocarbon production system

The present invention relates to an offshore hydrocarbon production system, and to various individual aspects thereof *per se*.

The production system according to the invention involves a surface production buoy holding a riser system in tension and achieves lightweight and structural simplicity by employing a seabed base or installation incorporating the control and manifold equipment for the system, an improved form of tethering of the production buoy to the seabed installation and a separate production support vessel in association with the buoy. This novel approach and design gives particular capital savings and running economy in very deep waters (e.g. of the order of 2000 metres), but can also be effective and advantageous in shallower waters such as in the North Sea. Gas and/or oil may be produced from one or more satellite subsea wells tied into the base mounted manifold. The riser system may be a slender system of vertical rigid steel conductor pipes held in tension by the surface production buoy tethered to the gravity base by synthetic plastics cables of limited elasticity, e.g. marine cables of aromatic polyamide such as "Kevlar".

The production support facility may be based on a flat-top barge fitted with thrusters and equipped to receive the hydrocarbon treatment modules, the utility modules, quarters, workshops, etc. The production support vessel may provide buffer oil storage. A shuttle tanker may be moored in tandem. Gas produced from the field may be recompressed and transmitted in the dense phase via a subsea line The production support vessel may initially be used as a pipe laying barge. This will be before the process and utilities modules have been installed on the deck of the barge.

One particular inventive aspect of the present system provides weight saving and simplicity in the support of services (e.g. fluid conductors, power lines, hydropneumatic umbilicals and the like) between a surface buoy and the seabed. To this end the control systems for a subsea manifold are placed subsea, rather than on the production buoy, allowing for a reduction in the number of service connections between the surface and the seabed. In one example of this a slender system of vertical rigid steel riser pipes are held in tension by a surface production buoy. The buoy is tethered to the base by high strength, low elasticity, low mass, buoyant pre-tensioned tethers made from a synthetic yarn.

The tethers are used to tension the risers in a manner previously disclosed in copending British Application 8330828.

The prime function of the buoy is to hold the riser assembly in tension in all sea states. The tension in the synthetic tethers is high, of the order of 20 to 40% of the ultimate breaking strain, and under tensions of this magnitude the essentially vertical, parallel tethers allow only minimal deflection of the buoy under extreme conditions, which may include mooring the production support vessel or a shuttle tanker to the buoy.

The hydrocarbon production system of the present invention also encompasses a subsea production manifold having mounted thereon one or more manifold control modules which may be operated from a surface production support vessel by means of one or more electro-hydraulic umbilicals.

Conventional subsea manifolds comingle the production from a number of satellite wells. Production from each well is controlled by variable orifice choke valves. These are placed in line along the length of the manifold and may be arranged on one or more horizontal levels. The system of the invention provides an improved subsea production manifold wherein pipework is arranged in circular loops with valves and diverters positioned so that their actuators point radially inwards. There may be one or more of these manifolds mounted on a base. At the centre of each individual manifold is a guide post which is usable for locating a remotely controlled maintenance tool. By lowering the tool down a guideline and on to the guide post each valve on any layer within the manifold may be removed for replacement or maintenance. Valves on different layers of a manifold according to this invention may be reached simply by moving the manipulator tool up or down the guide post. A further advantage of the radially arranged manifold is that not only can a malfunction in valves be serviced but the same tool may be deployed to operate valves.

A further aspect of the present invention relates to the multi-function role played by the production support vessel which is provided with an end derrick equipped with a motion compensated travelling block. Prior to production being started from the wells this vessel may be used for laying pipe; individual pipe sections may be joined by screwed joints whilst held in the vertical from the derrick and laid on the seabed in the vertical "J" mode. Once production is underway the derrick may allow the production support vessel to be used for changing-out buoy tethers, buoy maintenance, light workover on the well and any further necessary pipe laying.

As an alternative to mounting the derrick on a production support vessel it may be preferable to provide, according to this invention, a drilling derrick package which may be demountably attached on a suitable vessel, e.g. a diving support vessel (DSV). Such a drilling derrick is suitable for laying screw jointed pip-

ing in the "J" mode. In order to facilitate docking and other manoeuvres the drilling derrick may be made pivotable, thus reducing the superstructure height in the non-operating mode.

Thus, apart from the overall system, the present invention provides a number of individual component aspects *per se*, including a hydrocarbon production system having a production buoy tethered over an underwater base carrying the underwater manifold centre and the control equipment therefor. The invention also provides a buoy from which a service line or lines (e.g. an umbilical, a fluid conductor, riser or power line etc.) extend to the seabed, the buoy being tethered by vertical tensioned buoyant synthetic yarn tethers. It also provides an underwater manifold centre having an axis around which the valves are radially disposed for by service by a tool moveable into and out of the manifold along this axis; it further provides an underwater manifold centre having a service tool for operating the valves.

The invention also provides a production support vessel having a derrick mounted at an edge thereof, e.g. over a slipway or docking bay of the vessel. The invention also provides a diving support vessel having a demountable derrick unit thereon. The invention also provides J-laying screw-connected pipe,e.g. from such a production support or diving support vessel.

These and other independent aspects according to the invention, and an overall production system according to the invention, are illustrated by the following description of preferred embodiments to be taken in conjunction with the accompanying drawings in which like reference numerals indicate like items and in which:

Figure 1 is a schematic perspective view of an offshore production system according to the invention;

Figure 2 is a schematic perspective view of a production support vessel suitable for use in this system;

Figure 3 is a plan view of a seabed manifold system (SMS) suitable for use in the Figure 1 system; and

Figure 4 is an elevation view of the Figure 3 SMS showing simply the main loops thereof.

Whilst reference is frequently made herein to the sea and to the seabed, etc, it is to be understood that this is not limiting and that the invention and the equipment described generally and specifically herein are equally suitable for use in other large bodies of water.

The production system illustrated in Figure 1 is a production buoy secured by tethers to a subsea base on which are mounted the manifold and associated control modules for six satellite seabed wells (only one of which is shown) connected thereto by respective flowlines. The illustrated base is a gravity base, but, especially in relatively shallow water, might instead be piled. Production risers and umbilicals extend between the base and production buoy which communicates with the associated production support vessel via flexible flowlines and umbilicals at the water surface. The production support vessel can provide some buffer oil storage and offload on to a shuttle tanker. Gas is exported to shore via a seabed gas pipeline from the base.

The illustrated gravity base is a steel structure designed to be self floating for easy transportation to site. It has two cylindrical tanks arranged in a catamaran layout joined by a steel structure which is designed to be infilled with ballast. The dimensions are e.g. 40 metres by 23 metres and the submerged weight is e.g. 2000 tonnes. It will be understood that these and all other numerical valves quoted herein are purely exemplary.

A gravity base has been selected for this application to obviate the need for deepwater piling. The base has two principal functions; it acts as a mass anchor for the buoy, and it provides a suitable mounting point for the manifold structure and flowline tie-ins.

Each satellite well will be connected to the manifold by two (e.g. 4") flowlines and an hydraulic controls umbilical. The dual flowline allows the lines to be ball pigged as well as providing monitoring and annulus access functions.

The flowlines will be of the flexible type and will be designed for 5000 psi. working pressure and 10,000 psi test.

The control umbilicals will consist of hydraulic hoses with steel wire armour reinforcing.

The risers are two 6" and two 4" steel pipes, grade N80. One 6" line is dedicated for the product hydrocarbons and is sized to transmit 100 million standard cubic feet per day plus associated liquid condensate, and 12,000 barrels per day of crude oil. The initial throughput from a single well might be 50 million standard cubic feet per day, plus the associated liquids. The other 6" riser is dedicated to transmit dense phase recompressed gas back down to the manifold to the 10" seabed delivery line to shore.

The 4" lines of the riser assembly are available to circulate the various well service fluids down to the well, such as the pour point depressant, methanol when required, and well kill mud. They are also available for pigging manifold and flowlines if necessary. The individual riser pipes are connected to the manifold pipework at the riser foot.

No flexible joints are needed at the seabed manifold when the lines themselves are so long that any lateral displacement at the surface will have a negligible effect at the bottom. The riser pipes and the tethers do not have spacers or spiders to locate and hold them nor any profile forms,to minimise the current drag forces and effects.

The tethers are constructed over the major part of their length from the high strength synthetic yarn "Kevlar". This form of tether was developed for use in a deep marine environment. It has high strength, low elasticity, low mass and is buoyant or near buoyant in sea water. The bottom of the tether terminates in a section of chain of equivalent (300 ton) breaking strain. The tether is pulled down into a gravity lock. There are 8 tethers, each of 3-1/2" diameter and stressed up to a mean 22% of their ultimate breaking strain. Thus there is allowed a comfortable redundancy of at least two tethers. When recovering and inspecting tethers, they will be locked off and released in a sequence of opposite pairs. At the upper end of each tether is an 80 foot length of 2-5/8" abrasion resistant marine hauling chain. This passes up through the buoy and down over pulleys to be secured onto the top of the riser termination block. The chain is made from high quality steel, the links are flash butt welded. Each tether has an associated small diameter draw line which passes through the gravity lock in the base and is used to draw the tether back down into the lock after inspection or replacement. Although provision is made to inspect and/or replace the tethers, the theoretical life of the tethers at the low mean stress level chosen may exceed 15 years. The upper chain section can be expected to need replacement and provision is made to change-out the wearing section within the buoy.

The prime function of the buoy is to hold the riser assembly in tension in all sea states. The design parameters chosen are e.g. a 100 foot, 100 year return wave superimposed on a 10 foot tide. The permitted deflection criteria for the vertical drift under the influence of wind (100 mph) and tide (2 knot) is 4° from the vertical. This deflection is the deepwater drilling criterion, very conservative for the application.

The mass of the buoy needs to be 5 to 10 times the mass of the subsea elements. Keeping the riser assembly simple and having the tethers constructed from a light synthetic fibre has resulted, in the 6,000 feet case, in a buoy of a total operational mass of 2,000 tons. The mean total operational displacement is 3000 tons, and thus the mean tethering force is of the order of 1,000 tons. This tethering force is shared equally between the tethers and the riser.

The tethers are used to tension the riser. The tethers pass up through the buoy, over the chain wheels, back down to the riser where they are secured to the top of the riser terminal block. The tethers are pretensioned, along with the riser, by initial de-ballasting adjustments of the buoy. The wave and tide induced vertical movements of the buoy relative to and independent of the riser are partially suppressed by the sympathetic elastic contractions and extension of the tethers. The tethers (and riser) are pre-tensioned to an extent that even as the trough of the largest conceivable wave passes through, the residual tension in the riser is still greater than the weight of the riser. The individual tether tensions can be finely adjusted by vertically altering the height of the associated pulley using a screw mechanism.

Individual tethers have an associated chain stop mechanism to lock a chain to the buoy when it needs to be released from or reconnected to the riser for inspection or replacement.

The buoy, of steel construction, displaces 3,000 tons, has a ballasted mass of 2,000 tons and has a dockside weight of 600 tons. The general configuration is of a vertical dumb-bell with a moonpool. The lower section contains the ballasting tank and the ballasting system. The central columnar section spans the total range of the splash zone. This section has a reduced outside diameter to minimise the water plane area and thus minimise the wave induced tension changes in the tethers and riser. The upper section houses the chain wheels and the chain stops. The risers are connected through the top terminal block by flexible hoses which pass down into the moonpool from a simple tensioning equipment. The hoses are connected into a four position top manifold. The production support vessel hooks up its flexible floating hoses to whichever of the 4 positions suits the prevailing marine conditions.

The manifold may be connected to the riser by a conventional pressure sealing slip ring apparatus which allows for relative rotational movements of the riser and hoses. However, where working pressures in the riser and hoses are great, such sealing systems are prone to leakage and may well require extensive maintenance programmes. According to the invention the production buoy may be provided with a novel manifold connection arrangement in which a number of radially spaced individual make and break flow passages are provided for communication between a flowline and the riser. Under conditions where the flowline is "weather vaning" i.e. swivelling relative to the risers under the influence of wind and/or waves, a fluid-tight seal can be obtained at each radial position as the manifold body is circumscribed by the flowline. In order that fluid flow may be uninterrupted the make and break of these passages may be multi-plexed so that at least one passage is open at all positions.

As shown in Figures 1 and 2, the production support vessel 10 carries the hydrocarbon treatment plant to produce stablised crude suitable for tanker loading plus a dense phase gas (including the condensate) at 2,500 psi for pipeline transmission to the shore.

Dewatering the crude will not normally be

carried out on the process vessel. This is done at the onshore reception facility so as to avoid, or better regulate, any effluent problems.

The total operational power demand including power for electric thrusters is provided by a gas turbine generator set. Two 100% standby diesel generators are provided for use when the vessel is off station and for when it is operating in the pipelaying and maintenance roles.

Other utility services include firewater, instrument air, utility air, open drains, closed hydrocarbon drains, flare header and knock out pot. Potable water storage is provided but not potable water generation.

The gas product line can be pigged with an acid gel pig from shore to the production vessel which is provided with a pig receiver.

The production barge is provided with two pedestal cranes 12, 14; one at the stern is for flexible hose handling and for the maintenance inspection and replacement of the buoy mooring tethers. The second pedestal crane is available to offload supplies and chemicals when operating in a production support role. During pipe laying and riser maintenance a deck crane is used for pipe handling.

The drilling derrick 16 is equipped with a motion compensated travelling block and has a maximum working load capability of 250 tons, the maximum tension experienced during pipelaying.

The forward end module 18 comprises an accommodation unit, a multi-trade workshop, the marine control room and the process control rocm/laboratory.

The above-mentioned process and personnel modules are deck mounted. The compartments of the hull are used to house the generators, mud pumps and the mud tankage. Hull tanks are utilised to provide storage for about 4,000 tons of stabilised crude oil, fuel oil, potable water, methanol and other liquid chemicals.

Prior to the production modules 20 being skidded out the barge is used to lay the gas transmission line.

The standard pipe lengths will be welded onshore into double lengths, coated and wrapped for corrosion protection. The lengths will be taken out to the barge by a supply vessel on a regular basis. The line will be laid along a predetermined surveyed route from the barge using the drilling derrick to lay in the vertical "J" mode.

The individual sections will be joined by screwed joints (e.g. VAM joints) whilst held in the vertical from the derrick. The maximum tension pull in the derrick is 250 tons when operating at 2,000 metres. The maximum bend stress on the pipe is about 50% of the yield strength. The total operation of screwing, pressure testing and shrink wrapping over joint may be achieved at a rate of about 10 minutes per joint.

The subsea production manifold comingles the production from e.g. six satellite wells. Production hydrocarbons pass via 4" flowlines through chokes into a 6" line and thence into the riser.

Production from each well is controlled in the manifold control modules by variable orifice choke valves.

As shown in Figures 3 and 4 the manifold 30 has a service loop which will permit individual well flowlines to be pigged; the pigs being directed down the required flowline by diverters. The service loop also permits testing of individual wells without interruption to the operation of the others.

In the manifold pipework is arranged in circular loops 32 with valves and diverters 34 positioned so that their actuators point radially inwards. At the centre is a large diameter guide post 36 which is used for locating a remotely controlled maintenance tool 38. In the event of a valve malfunction the tool would be deployed down a guide line and landed on the base. The manipulator fitted to the tool would then remove the valve to the surface for repair. A replacement valve could be carried down and fitted on the same trip to reduce downtime to a minimum.

The manifold pipework and its supporting steel framework is designed to remain on the seabed and last the anticipated life of the field.

A particular advantage of this arrangement is that the maintenance tool may be used to operate valves as well as to service them.

CLAIMS

1. An offshore hydrocarbon production system comprising a subsea manifold connectable to one or more wells, and a riser extending from the manifold to a surface buoy which is tethered over the manifold and maintains the riser in tension.

2. A system according to claim 1 wherein control equipment for the manifold is disposed subsea.

3. A system according to claim 1 or 2 including a production support vessel in association with the buoy.

4. A hydrocarbon production manifold for subsea use having valves disposed radially around a manifold axis for servicing and/or actuating by a tool moveable into and out of the manifold along this axis.

5. A manifold according to claim 4 having a central guidepost for locating a remotely controlled such tool.

6. One or more manifolds according to claim 4 or 5 mounted on a subsea base.

7. A production system according to any of claims 1 to 3 wherein the subsea manifold is according to any of claims 4 to 6.

8. A hydrocarbon production system according to claim 1 and substantially as herein-

before described with reference to the accompanying drawings.

9. A subsea production manifold substantially as hereinbefore described with reference to Figs. 3 and 4 of the accompanying drawings.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd, Dd 8991685, 1987.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.